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R. Vogt

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Ramona Vogt [1]

Lawrence Livermore National Laboratory, Livermore, CA 94551 USA
Physics. Department, UC Davis, Davis, CA 95616 USA

Abstract

The J/ψ, ψ' and χ_c production yields are expected to be considerably suppressed in a quark-gluon plasma. In addition, the Υ states, with the possible execption of the $1S$ state, are also expected to be suppressed. However, in proton-nucleus collisions all the quarkonium production cross sections scale less than linearly with the number of binary nucleon-nucleon collisions. These "cold nuclear matter" effects need to be accounted for before signals of the high density QCD medium can be identified in the measurements made in nucleus-nucleus collisions. There are two cold nuclear matter effects important for midrapidity quarkonium production: "nuclear absorption", a final-state effect, and shadowing, an initial-state effect. We characterize these effects and study their energy and rapidity dependence.

Key words: quarkonium, heavy-ion collisions
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The NA50 experiment at the CERN-SPS made a detailed study of J/ψ and ψ' production in fixed-target proton-nucleus collisions with incident protons of 400 and 450 GeV, employing six different nuclear targets [1,2]. Comparing the production cross sections measured at 400 GeV to Glauber calculations neglecting nuclear modifications of the parton densities, the J/ψ "absorption cross section" was determined to be $\sigma_{\rm abs}^{J/\psi} = 4.6 \pm 0.6$ mb [1]. A value of $\sigma_{\rm abs}^{\rm J/\psi} = 4.2 \pm 0.5$ mb, extracted from a global fit to the 400 and 450 GeV J/ψ to Drell-Yan ratios, has been used by NA50 [3] and NA60 [4] in the studies of the SPS heavy-ion data, collected at 158 GeV, assuming that $\sigma_{\rm abs}^{J/\psi}$ is a

Email address: vogt@physics.ucdavis.edu (Ramona Vogt).
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"universal quantity", insensitive to the collision energy and rapidity acceptance. However, E866, at FNAL, observed less J/ψ absorption at 800 GeV than NA50 in the same $x_{\rm F} \sim 0$ region. In terms of the very simple "α parametrisation", $\sigma_{\rm p\,A} = \sigma_0 A^\alpha$, NA50 reported $\alpha = 0.925 \pm 0.009$ at 400 GeV [1] while E866 obtained $\alpha \sim 0.95$ [5]. We have studied final-state absorption with a number of parameterizations of initial-state shadowing. We find a non-negligible $\sqrt{s_{_{NN}}}$ dependence on the absorption, even without shadowing [6].

The absorption cross section crucially depends on whether the PDFs are those of a free nucleon or of a nucleon in a nucleus. For instance, at SPS energies we obtain the same J/ψ nuclear absorption pattern using proton PDFs with $\sigma_{\rm abs}^{J/\psi} = 4.5$ mb as using EKS98 with $\sigma_{\rm abs}^{\rm J/\psi} = 7$ mb [6]. If the enhancement due to initial-state antishadowing is ignored, a weaker final-state "effective" absorption is sufficient to obtain the same result.

Other nuclear effects are likely to be present and should be considered in a detailed study of all "cold nuclear effects". In particular, the charmonium yields measured by E866 are more suppressed at forward x_F than at $x_{\rm F} = 0$ [5]. In the "midrapidity region", nuclear effects other than shadowing and absorption may be neglected [7]. As in most previous studies of charmonium absorption in nuclear matter, we treat the J/ψ as a single meson passing through the nuclear medium.

When shadowing is taken into account, $\sigma_{\rm abs}^{J/\psi}$ significantly depends on the rapidity of the J/ψ, even within a relatively narrow window around midrapidity. In particular, the J/ψ nuclear dependence determined by E866 in the region $-0.1 < x_{\rm F} < +0.2$ only looks independent of x_F if shadowing is neglected. Furthermore, the level of J/ψ absorption at midrapidity significantly decreases with collision energy. While the specific numerical values depend on the nPDFs, the $\sigma_{\rm abs}^{J/\psi}$ dependence on energy is a general feature, independent of shadowing effects. Without shadowing, in $0 < y_{\rm cms} < 1$, $\sigma_{\rm abs}^{J/\psi} = 5.5 \pm 0.8$ mb at 158 GeV, increasing to 7.2 ± 0.5 mb with EKS98 [6]. At RHIC, the momentum fractions probed are considerably smaller than at fixed-target energies. Our energy dependence suggests that $\sigma_{\rm abs}^{J/\psi} < 1$ mb at $\sqrt{s_{_{NN}}} = 200$ GeV.

In this scenario, at LHC energies, absorption should be negligible and initial-state shadowing the only effect in the rapidity range of the LHC detectors. If both the pA and pp data are taken at the same $\sqrt{s_{_{NN}}}$, the same x values will be probed in the nucleus and in the proton. Such same energy comparison runs would be an excellent probe of the nuclear gluon distributions because $pA(\sqrt{s_{_{NN}}})/pp(\sqrt{s_{_{NN}}}) \propto f_g^A(x,\mu^2)/f_g^p(x,\mu^2)$. However, if the pA and pp data are taken at different energies (and x values), extraction of the nuclear gluon density is less straightforward since $pA(\sqrt{s_{_{NN}}})/pp(\sqrt{s}) \propto f_g^A(x',\mu^2)/f_g^p(x,\mu^2)$. The approximate A dependence of the total cross section relative to the pp cross section, assuming no other cold matter effects, is $\alpha(pA/pp) \sim 1 + \ln[f_g^A(x_2',\mu^2)/f_g^p(x_2,\mu^2)]/\ln A$ where $x_2' = x_2$ if $\sqrt{s}$ is the same for the two systems. In pPb relative to pp collisions at 5.5 TeV, $\alpha \sim 0.76$ for J/ψ and ~ 0.88 for Υ [8].

We show predictions of the J/ψ and Υ production ratios as a function of rapidity for cold nuclear matter effects at the LHC. If pA and pp data can be taken at the same energy, as at RHIC, it is easier to make comparisons. However, the LHC setup makes this ideal situation more difficult. At the nominal injection energy, the proton beam energy is 7 TeV while the nuclear beam energy per nucleon is lower by the nuclear charge-to-mass ratio, Z/A. To make a pp comparison without relying on calculations, the pp collisions have to be run at the pA per nucleon energy, decreasing the luminosity. It may be necessary to rely on 14 TeV pp reference data, at least initially. However, when a 7 TeV proton beam collides with a $7(Z/A)$ TeV per nucleon ion beam, in the "equal-speed frame", the center-of-mass rapidity is displaced by $\Delta y_{\rm cm}^{pA}$, ~ 0.5 in pPb collisions.

Figure 1 shows the ratios for cold nuclear matter effects on pA collisions at the LHC. We first show pPb/pp ratios at the same $\sqrt{s_{_{NN}}}$ for both systems. We next show the pPb/pp ratios with respect to pp collisions at $\sqrt{s} = 14$ TeV with $\Delta y_{\rm cm}^{pA} = 0$. The final pPb calculations shown are in the equal-speed frame with finite $\Delta y_{\rm cm}^{pA}$ relative to the 14 TeV pp results.

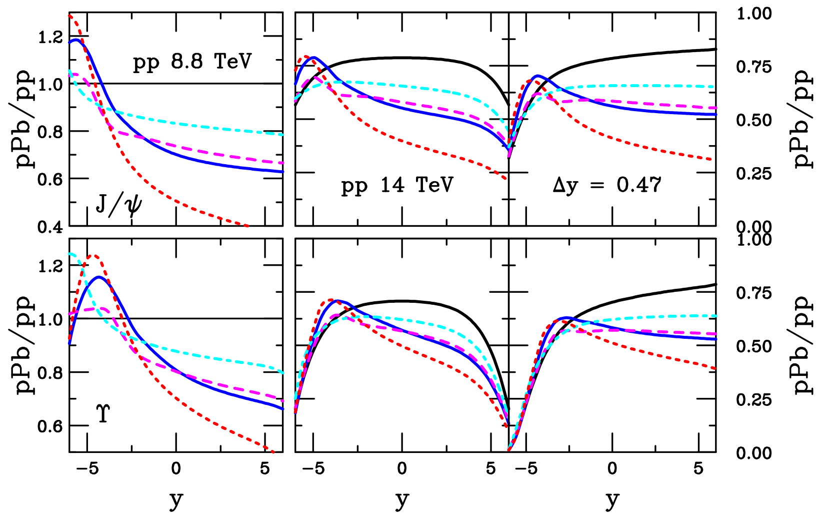

Fig. 1. The pPb/pp ratios for J/ψ (top) and Υ (bottom) production at 8.8 TeV for: pPb and pp collisions at the same center-of-mass energy and $\Delta y = 0$ (left); the pp reference at 14 TeV with $\Delta y = 0$ (center); and the higher energy pp reference and pPb rapidity shift in the equal-speed frame taken into account (right). The curves show EKS98 (solid), nDSg (dashed), HKN (dot-dashed) and EPS08 (dotted) shadowing parameterizations with no nuclear absorption. The upper solid curves in the center and right panels show the ratios with no shadowing.

Current shadowing parameterizations exhibit a wide variation in the low x nuclear gluon density, outside the range of present analyses based on data at higher x and low Q^2. With eA data, the nuclear gluon densities could be more precisely determined. If nuclear absorption is indeed negligible at LHC energies, J/ψ and Υ production can be used to study the scale dependence of the gluon density, in protons and nuclei.

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